Non-edible Vegetable Oil Based Biodiesel: An Eco-friendly and Sustainable Product

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***Abstract*— This study explores biodiesel as a renewable and environmentally friendly alternative to fossil fuels, with a focus on feedstock evolution, production processes, properties, advantages, and environmental impacts. It begins by categorizing biodiesel feedstocks into first, second, third, and fourth generations. First-generation feedstocks, derived from edible oils, present challenges related to food security and land use. Second-generation feedstocks, which include non-edible oils and waste materials, offer improved sustainability by reducing competition with food production. Third-generation feedstocks, primarily algae, provide high oil yields and do not require arable land, while fourth-generation feedstocks involve genetically engineered organisms and carbon capture technologies aimed at minimizing environmental impact. Various biodiesel production processes, including pyrolysis, microemulsion, and transesterification, are considered. Transesterification is the most widely accepted due to its efficiency and simplicity, while pyrolysis and microemulsion offer additional methods for converting biomass into fuel. The study also discusses biodiesel's properties, such as high lubricity, biodegradability, and compatibility with existing diesel engines. The advantages of biodiesel are highlighted, particularly its ability to improve air quality, and decrease reliance on fossil fuels. However, concerns about the environmental impact of large-scale feedstock cultivation, especially in first-generation biodiesel, are addressed. Ultimately, biodiesel presents a promising path toward reducing environmental damage and meeting global energy needs in a more sustainable manner.**

Keywords—Non-edible feedstocks, biodiesel, Transesterification, biodiesel Properties, Biodiesel and Environment.

1. INTRODUCTION

With the modernization as well as industrial growth in all geographical regions of the world, the requirement of petroleum based energy resources is increasing exponentially. But these reserves resources are limited and depleting day by day. This has led to exploring environment friendly, renewable, non-conventional energy sources. Biodiesel offers a very good alternative to petroleum based energy resources. It is environment friendly and also sustainable. Biodiesel can be produced from straight vegetable oil (edible and non-edible both), animal fats and waste cooking oil. It is used as a replacement for or additive to diesel fuel. The interest of researchers in biodiesel has grown significantly due to its potential to minimize greenhouse gas emissions, air pollution and dependency on fossil fuel. The development of biodiesel has evolved in multiple stages, each addressing specific challenges and improving upon the sustainability and efficiency of the previous. These stages are first, second, third and fourth generation. In first generation, the primary feed-stocks are edible oils such as mustard oil, soybean oil, sunflower oil, palm oil etc. In second generation, the primary feed-stocks are non-edible oils such as Argemone Mexicana oil, Jatropha oil etc. It also includes waste cooking oil, animal fats etc. In third generation, algae are the primary feed-stock. In fourth generation, the researcher focuses on genetically engineered plants and micro organisms developed for higher yields of biodiesel.

The progress of biodiesel as of first to fourth generation represents a progressive swing towards more efficient, sustainable and environmentally friendly fuel production. Each generation has addressed detailed challenges, from food vs. fuel war in the first generation to the technological advancements required for algae and genetically modified organisms in the third and fourth generations. As the world continues to hunt for alternatives to fossil fuels, biodiesel stands out as a promising option, offering a pathway for promoting energy security, reducing greenhouse gas emissions and fostering a more sustainable future. However, achieving the full potential of biodiesel will need ongoing researches, technological innovations, and careful consideration of environmental and socioeconomic impacts.

Table 1: Modern transportation fuels: Present and Future

Fuel Type Availability	Current	Future
Gasoline	Excellent	Moderate – Poor
Biodiesel	Moderate	Excellent
Compressed Natural Gas (CNG)	Excellent	Moderate
Hydrogen Fuel Cell	Poor	Excellent

2. MATERIALS AND METHODS:

2.1 First Generation Feed-Stock:

Feed-stocks for biodiesel production of first generation are food crops such as soybean oil, rapeseed oil, palm oil, sunflower oil etc. It uses the established supply chain system for the production of feed-stocks. This provides an additional revenue generation for farmers and reduces the waste due to high yield. First generation feed-stocks play a decisive role in the biodiesel production, but their sustainability and ethical implications require a careful balance between energy production and food security.

2.2 First Second Generation Feed-Stock:

Second generation feed-stocks represent a significant advancement in biodiesel production, addressing many limitations associated with first-generation feed-stocks. Unlike first generation feed-stocks, which primarily consist of edible oils, second generation feed-stocks are derived from non-edible sources. This shift towards non-food crops and waste materials enhances sustainability by avoiding competition with food supplies and mitigating the environmental impact associated with traditional agriculture. Second generation feed-stocks can be categorized into Non-Edible vegetable oils (e.g. Jatropha curcas, Pongamia pinnata, Camelina sativa etc.), Waste Cooking Oils, Animal Fats etc. Their cultivation often requires less water and fewer inputs like fertilizers and pesticides, leading to a lower environmental impact. The diversity of second generation feed-stocks offers flexibility in biodiesel production, allowing for regional adaptation based on the availability of specific resources. This diversity also reduces dependency on a single type of feedstock, enhancing energy security and sustainability. Many second generation feed-stocks can be grown on lands unsuitable for food production. This reduces land-use pressure, contributing to a circular economy. The future of second generation feed-stocks in biodiesel production looks promising, with ongoing research focused on overcoming the existing challenges. The development of more efficient conversion processes, are expected to lower costs and improve yields.

2.3 Third Generation Feed-Stock:

The quest for sustainable and efficient biodiesel production has led to the development of third generation feed-stocks, primarily focused on algae and other advanced bioresources such as microalgae. Unlike first- and second generation feed-stocks, which utilize food crops or non-food plants and waste materials, third generation feed-stocks are derived from high-yielding, rapidly renewable resources that offer greater environmental benefits and reduced competition with food production. This generation of feed-stocks holds immense potential to overcome the limitations of earlier generations, driving the future of biodiesel production towards greater efficiency and sustainability. Advantages of third generation Feed-stocks are high productivity, non-competitive with food supply, CO_2 mitigation, reduced environmental impact etc. Despite their numerous advantages, third generation feed-stocks face several significant challenges that currently limit their widespread adoption such as high production costs, technological barriers for scale-up production, sustainable resource availability, processing complexity etc.

2.4 Fourth Generation Feed-Stock:

Fourth generation feed-stocks for biodiesel production represent the most advanced stage in biodiesel technology, focusing not only on the sustainability of the feedstock itself but also on the environmental impact of the entire production process. These feed-stocks are often associated with cutting-edge technologies such as genetically engineered organisms, photosynthetic microbes, carbon capture and utilization (CCU) etc. Unlike earlier generations, which primarily focused on improving the efficiency and sustainability of feed-stocks, fourth generation biodiesel aim to achieve carbon-negative production, where more CO_2 is absorbed or utilized than is emitted during the entire lifecycle of the fuel. Apart from numerous advantages, , there are also several challenges that need to be addressed such as high development cost, technological complexity, regulatory and ethical concerns, energy and resource Intensity, public perception and acceptance etc.

Table 2: Oil Sources

Vegetable oils (Edible)	Non-edible oils	Animal Fats	Other Sources
Soybeans	Argemone	Lard	Bacteria

	Mexicana		
Rapeseed	Almond	Tallow	Algae
Canola	Abutilon muticum	Poultry Fat	Fungi
Safflower	Andiroba	Fishoil	Micro algae
Barley	Babassu		Tarpenes
Coconut	Brassica carinata		Latexes
Copra	B. napus		Cooking Oil (Yellow Grease)
Cotton seed	Camelina		Microalgae (Chlorellavulgaris)
Groundnut	Cumaru		
Oat	Cynara cardunculus		
Rice	Jatrophacurcas		
Sorghum	Jatropha nana		
Wheat	Jojoba oil		
Winter rapeseed oil	Pongamiaglabra		
Mustard	Laurel		
	Lesquerellafendleri		
	Mahua		
	Piqui		
	Palm		
	Karang		
	Tobacco seed		
	Rubber plant		
	Rice bran		
	Sesame		
	Salmon oil		

2.5 Biodiesel Production Process

Significant efforts have been made to establish vegetable oils and blends that approximate the properties as well as performance of hydrocarbons-based petroleum diesel fuels. The problem with substituting vegetable oils for diesel fuel is generally associated with elevated viscosity, low volatility along with polyunsaturated properties. These can be changed in several ways:

*2.5.1 **Straight Use and Blending***

Straight vegetable oil (SVO) refers to the unprocessed or minimally processed oil extracted from various plant sources like soybeans, canola, jatropha, palm etc. Historically, vegetable oils were considered by Rudolf Diesel, the inventor of the diesel engine, as potential fuels for his engine, which was originally designed to run on peanut oil. Be that as it may, the rise of petroleum-based diesel in the 20th century dominated the utilize of SVO as a fuel source. The revival of interest in vegetable oils as fuels has emerged largely due to environmental concerns and the volatility of fossil fuel prices. Vegetable oils possess several characteristics that make them appealing for direct use in diesel engines. They are biodegradable, non-toxic, and renewable. Moreover, vegetable oils have a high cetane number, which is a measure of the combustion quality of diesel fuels during compression ignition. Despite these advantages, straight vegetable oils have several limitations when used directly in diesel engines without modification. One of the primary challenges of using SVO is its high viscosity, which is significantly greater than that of conventional diesel fuel. This increased viscosity can lead to incomplete atomization during the fuel injection process, resulting in poor combustion efficiency. High viscosity also contributes to the formation of carbon deposits on injectors, pistons, and valves, which can impair engine performance over time. Most vegetable oils have higher pour points and cloud points compared to diesel, meaning they tend to gel or solidify at lower temperatures. This can cause fuel filter clogging and hinder fuel flow, particularly in colder climates. To address these issues, modifications to diesel engines are often required when running on straight vegetable oil. Preheating the oil before injection can help reduce viscosity and improve combustion. Some systems use dual-tank setups, where the engine starts and stops on conventional diesel but switches to preheated vegetable oil during operation. While such modifications can enhance the use of SVO, they can be costly and complex for widespread adoption.

Blending vegetable oils with conventional diesel offers a more practical approach for utilizing vegetable oils as biodiesel. By blending, the issues related to high viscosity and poor cold flow properties of straight vegetable oils can be mitigated while still reaping the environmental and economic benefits of biodiesel. Blending involves mixing vegetable oils with diesel in various proportions, typically ranging from 5% to 50%, with the most common blends being B5 (5% biodiesel, 95% diesel) and B20 (20% biodiesel, 80% diesel). These blends can often be used in diesel engines without significant modifications, making them an attractive option for immediate implementation.

*2.5.2 **Pyrolysis***

Pyrolysis is a thermochemical process used in biodiesel production that involves the decomposition of organic material, such as biomass or waste oils, at elevated temperatures in the absence of air or oxygen. The process typically occurs between 300°C and 900°C and leads to the breakdown of complex molecules into simpler ones. In the context of biodiesel production, pyrolysis converts waste vegetable oils, animal fats, or non-edible oils into hydrocarbons that can be further refined into biodiesel. This method is advantageous because it allows the use of low-value feedstocks, reduces waste, and can yield high-quality biofuels with properties similar to conventional diesel. Pyrolysis is considered a sustainable alternative to traditional fossil fuel extraction, supporting the circular economy by utilizing waste materials for energy production.

*2.5.3 **Microemulsion***

Microemulsion is an innovative technique for biodiesel production that involves the dispersion of vegetable oil in a mixture of alcohol, surfactants, and co-surfactants to form a thermodynamically stable microemulsion. This process facilitates the reduction of vegetable oil's viscosity, enabling it to be used directly as a fuel in diesel engines without requiring full transesterification. The microemulsion acts as a fluid mixture where the vegetable oil and alcohol are finely dispersed, allowing for improved combustion properties and better fuel performance. Additionally, it can significantly reduce exhaust emissions compared to unprocessed oils. While microemulsion-based biodiesel production is relatively simple and cost-effective, the long-term engine performance and stability of the emulsion are areas of ongoing research. Nonetheless, it presents a viable option for utilizing vegetable oils, especially non-edible ones, in biodiesel production.

2.5.4 *Transesterification*

Transesterification is the most extensively used chemical process for biodiesel production, where triglycerides setup in vegetable oils or animal fats react with an alcohol, generally methanol or ethanol, in the presence of a catalyst such as sodium or potassium hydroxide. This reaction breaks the triglycerides into glycerol and methyl or ethyl esters, which are the chemical compounds that make up biodiesel. Transesterification comprises of a number of progressive, reversible responses. The triglycerides are changed step canny to diglycerides, monoglyceride and at last glycerol and ester. A mole of ester is librated at each step. The process is efficient and can yield high-purity biodiesel that closely mimics the properties of conventional diesel fuel, making it suitable for use in existing diesel engines without modifications. The glycerol produced as a by-product can also be utilized in other industries, contributing to the overall sustainability of the process. Transesterification is preferred due to its simplicity, effectiveness, and ability to convert a wide range of feedstocks into biodiesel, including non-edible oils and waste fats, enhancing its potential for large-scale biodiesel production.

Transesterification reactions are as follows:

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$$\text{Triglycerides} + \text{ROH} \xrightarrow{\text{catalyst}} \text{Diglycerides} + \text{R'COOR}$$

$$\text{Diglycerides} + \text{ROH} \xrightarrow{\text{catalyst}} \text{Monoglycerides} + \text{R''COOR}$$

$$\text{Monoglycerides} + \text{ROH} \xrightarrow{\text{catalyst}} \text{Glycerol} + \text{R'''COOR}$$

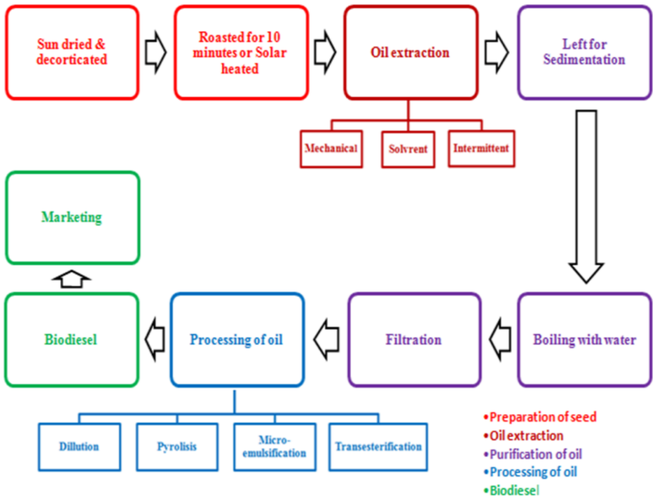

Figure1: Flow chart for Biodiesel Production

2.6 *Biodiesel Properties*

Biodiesel are characterized by their physical properties. These properties are all specified through the biodiesel standard. These standard identities are determined by using standard test methods and compared with European (EN 14214), USA (ASTM D6751), India (BIS) and Germany (DIN 51606) organization. This standard identifies or parameters the pure biodiesel (B100) must congregate before being used like a pure fuel or being blended with petroleum diesel fuel.

2.6.1 *Viscosity*

Viscosity is the most vital property of biodiesel because the operation of fuel injection equipment depends on it. Particularly at low temperature, the fluidity of the fuel is affected by an increase in viscosity. High viscosity leads to inferior atomization of the fuel spray as well as poor operation of the fuel injectors. As the oil temperature increases its viscosity decreases.

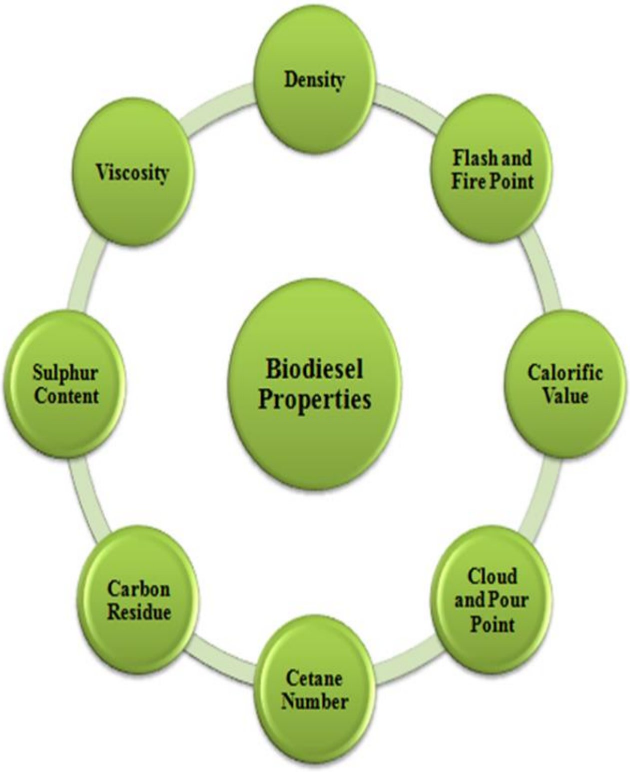

Figure2: Schematic diagram showing properties of Biodiesel

2.6.2 *Density*

Density is the mass per unit volume of liquid. The density of diesel fuel oil is vital because it gives clue of the delay or time lag between the injection and start of combustion of the fuel in a diesel engine. It also gives the indication of the energy per unit mass or specific energy. The efficiency of atomization of fuel depends on the density.

of the fuel injectors. As the oil temperature increases its viscosity decreases.

2.6.3 *Flash and Fire Point*

Flash point is also one of the important properties. Flash point of a fuel gives an idea of temperature at which the fuel will first ignite on exposing to a flame or spark. It is the minimum temperature at which fuel ignites with enough vapors. Flash point depends on the fuel's volatility as volatility increases, flash point decreases. Fire point is slightly higher than the flash point. It refers to the lowest temperature at which the fuel produces enough vapor to sustain continuous combustion after being ignited. The fuel will keep burning even after the ignition source is removed.

2.6.4 *Calorific Value*

The calorific value of a fuel is the amount of energy released when a specific amount of fuel is completely combusted. Calorific esteem is a vital parameter in the determination of a fuel. The calorific esteem of biodiesel is lower than of diesel since of higher oxygen substance.

2.6.5 *Cloud and Pour Point*

In low temperature applications environment, the cloud and pour point of fuel are having vital role. The cloud point is the lowest temperature at which a cloud like things of wax crystals first appears when the fuel is cooled in controlled circumstance amid a standard test. The pour point is the minimum temperature where the fuel can flow. It is the lowest temperature at which the amount of wax shaped in a fuel is satisfactory to gel the fuel.

2.6.6 *Cetane Number*

The Cetane Number provides information about the ignition delay time of a fuel on injection into the combustion chamber. It is a measure of the ignition quality of the fuel. High cetane number means short ignition delay. Fuels having low cetane number, show increased particulate matter exhaust emissions due to fuel incomplete combustion.

2.6.7 *Carbon Residue*

Carbon residue is formed by decomposition and successive pyrolysis of the fuel. It causes clogging of the fuel injectors. Carbon residue test is an indicator of the level of deposits resulting from the fuel combustion.

2.6.8 *Sulphur Content*

Sulphur content of the fuel is important parameter for engine operability. It causes emissions of oxides of sulphur in exhaust. Biodiesel produced from most of the vegetable oils and animal fats have low sulphur content.

3. BIODIESEL ADVANTAGES:

The biggest advantage of biodiesel incorporates its potential for bringing down reliance on imported natural petroleum, inherent lubricity of biodiesel, biodegradability, and its domestic origin. It is readily available, renewable, having higher combustion efficiency, contains lower sulphur, has high aromatic content and high cetane number.

3.1 Availability and Renewability of Biodiesel

The feedstock for biodiesel can be locally produced. In comparison to petroleum diesel, the risk of transporting, handling and storing are much easier.

3.2 Biodegradability of biodiesel

Biodiesel is environmentally friendly and biodegradable which leads to solution for waste problem. Therefore, interest is continuously growing in it than conventional diesel. Biodiesel is nontoxic and its oxygen content enhances the biodegradation process. It is reported that biodiesel is highly biodegradable in soil environment as well as aquatic environment.

3.3 Higher Lubricity

Biodiesel reduces long term engine wear and tear. Methyl esters in biodiesel improve lubricating property. The performances of fuel injectors and fuel pumps are enhanced when biodiesels are used. The components like crank case which are lubricated through fuel are showing reduced frictional wear.

3.4 Lower emissions from Biodiesel

The biodiesel impacts greatly on engine exhaust emissions and it is reported that vehicular engine is highest polluter globally. The reasons behind lower emissions are oxygen content, less sulphur content, less particulate matter etc. Presence of oxygen in biodiesel reduces hydrocarbons and carbon mono oxides in exhaust gases.

4. Biodiesel and Environmental Concern:

Derived from renewable resources such as vegetable oils and animal fats, biodiesel is a clean-burning fuel that offers several environmental benefits compared to petroleum-based diesel. One of its most significant advantages is its contribution to reducing greenhouse gas emissions. Unlike fossil fuels, biodiesel combustion releases lower levels of carbon dioxide, sulfur dioxide, and particulate matter. This characteristic makes it an attractive option for addressing global climate change, as it can mitigate the harmful effects of carbon emissions in the atmosphere. Furthermore, biodiesel has the potential to be carbon-neutral since the plants used to produce it absorb carbon dioxide during their growth cycle, offsetting the emissions generated during combustion. Diesel engines are known for emitting high levels of nitrogen oxides (NOx), particulate matter (PM), and sulfur compounds, which contribute to air pollution and respiratory problems. Biodiesel, especially when used in blends with traditional diesel, significantly reduces these harmful pollutants. Studies have shown that biodiesel can reduce particulate emissions by as much as 50%, while also lowering the release of toxic air contaminants. As a result, biodiesel can improve urban air quality and help protect public health, particularly in densely populated areas where vehicle emissions are a major concern. Biodiesel production, on the other hand, typically involves the use of non-toxic, biodegradable materials, which reduces the risk of environmental damage. Moreover, biodiesel can be produced locally, reducing the need for transporting fuel over long distances, which in turn decreases the energy consumption and carbon emissions associated with fuel transportation.

Conclusion

Biodiesel represents a promising alternative to traditional petroleum fuels, with its potential to address global energy demands while mitigating the environmental concerns associated with conventional diesel. The classification of biodiesel feedstocks into first, second, third, and fourth generations underscores the ongoing innovation in this field. Biodiesel production processes such as pyrolysis, microemulsion, and transesterification play a critical role in converting raw feedstocks into usable fuel. Among these methods, transesterification is the most commonly employed process due to its simplicity, efficiency, and cost-effectiveness. The continuous refinement of these production processes is essential to improving the economic viability and environmental sustainability of biodiesel production, particularly as the industry seeks to scale up to meet growing global demand. The properties of biodiesel, such as its higher lubricity, flash point, and biodegradability, make it a suitable replacement for conventional diesel in various applications. Biodiesel's compatibility with existing diesel engines is a significant advantage, as it allows for a relatively seamless transition to more sustainable fuel options. Moreover, its ability to reduce harmful emissions, such as carbon dioxide, sulfur oxides, and particulate matter, makes it a cleaner-burning fuel, contributing to improved air quality and reduced environmental degradation. Despite its many advantages, biodiesel is not without challenges. However, the advantages of biodiesel, such as its renewability, reduction of greenhouse gas emissions, and potential for domestic production, far outweigh these challenges when managed responsibly. In addressing environmental concerns, biodiesel's role in reducing carbon emissions, improving air quality, and mitigating climate change is undeniable. However, the future of biodiesel will depend heavily on the continued development of sustainable feedstocks, advancements in production technology, and the establishment of policies that promote environmentally responsible practices.

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